NOTES

Dusting roots of *Abies concolor* and other conifers with *Pisolithus tinctorius* spores at outplanting time proves ineffective[1]

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Received September 28, 1982[2]
Accepted April 11, 1983

ALVAREZ, I. F., and J. M. TRAPPE. 1983. Dusting roots of *Abies concolor* and other conifers with *Pisolithus tinctorius* spores at outplanting time proves ineffective. Can. J. For. Res. **13**: 1021–1023.

Dusting roots of white fir (*Abies concolor* (Gord. & Glend.) Lindl.), shasta red fir (*Abies magnifica* var. *shastensis* Lemm.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) with *Pisolithus tinctorius* (Pers.) Coker & Couch (*Pt*) spores when outplanted produced no *Pt* mycorrhizae at the end of the first growing season. In the 3rd year occasional *Pt* mycorrhizae had formed on white fir. Inoculations reduced seedling survival in some cases. High rate of spore application may have desiccated roots of the true firs; levels of spore application need careful attention. Soil scarification and ripping significantly promoted growth of white fir seedlings compared with scarification alone.

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Le saupoudrage de spores de *Pisolithus tinctorius* (Pers.) Coker & Couch sur des racines d'*Abies concolor* (Gord. & Glend.) Lindl., d'*Abies magnifica* var. *shastensis* Lemm., de *Pseudotsuga menziesii* (Mirb.) Franco et de *Pinus ponderosa* Dougl. ex Laws. lors du transplant n'a pas produit de mycorhizes à la fin de la première saison de croissance. À la 3ème année, quelques mycorhizes à *P. tinctorius* se sont formées sur *A. concolor*. Dans quelques cas, les inoculations ont abaissé le niveau de survivance des semis. Une application concentrée de spores peut avoir engendré une dessiccation des racines des sapins (*Abies*); les concentrations de spores à l'application doivent faire l'objet d'une attention particulière. La scarification du sol avec accroc a favorisé de façon significative la croissance des semis d'*A. concolor* par rapport à la seule scarification.

[Traduit par le journal]

Introduction

True firs constitute about one-fourth of the commercial sawtimber in California, but research on them has been fragmentary and often incidental to studies of other species. For many years forest managers considered these species less desirable than other conifers (Gordon 1970). Commercial acceptance of white fir (*Abies concolor* (Gord. & Glend.) Lindl.) led to increasing interest in its artificial regeneration and the realization of its erratic performance when outplanted. Literature on field survival of white fir is scarce, but values varying from 16 to 76% (Adams 1961, 1962) have been reported for 2-0 stock and 5% (Adams 1962) for 1-0 stock. Knowledge of white fir physiology is limited, so its erratic field performance cannot be explained.

Because mycorrhizal fungi improve field survival and growth of outplanted seedlings (Marx 1980) our study was undertaken to determine (*a*) whether inoculation of bare-root or containerized seedlings with spores of *Pisolithus tinctorius* (Pers.) Coker & Couch (*Pt*) immediately before outplanting results in mycorrhiza formation and (*b*) whether mycorrhizae thus formed affect subsequent survival and growth of white fir seedlings. The study sites included three areas in northern California as well as different types of planting stock and site preparation (Table 1). In one study area, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and shasta red fir (*Abies magnifica* var. *shastensis* Lemm.) were included in the study.

Materials and methods

The studies were established in plantations of W. H. Beaty

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[1] Oregon Agricultural Experiment Station Technical Paper No. 6538.

[2] Revised manuscript received April 5, 1983.

TABLE 1. First year survival (percent) of seedlings inoculated with *Pisolithus tinctorius* spores at time of outplanting

Location	Species	Type of planting stock	Survival % 1st growing season[d]	
			Control	Inoculated
Westwood[b]	White fir	1-0 bare root	73	41**
Westwood[c]	White fir	1-0 bare root	74	46*
Mooreville[d]	White fir	1-0 container	73	69
McCloud[a]	White fir	2-0 bare root	82	80
McCloud[a]	Ponderosa pine	1-0 bare root	100	92
McCloud[a]	Douglas-fir	2-0 bare root	85	95
McCloud[a]	Red fir	2-0 bare root	93	80**

[a] Site scarified.

[b] Site scarified plus ripped.

[c] Clear-cut, no site preparation.

[d] Significant differences between control and inoculated seedlings at $P \leqq 0.05$ (*) or 0.01 (**).

and Associates Inc., near Westwood, Lassen County; Champion International Co., McCloud, Siskiyou County; and Soper-Wheeler Co., Mooreville, Yuba County. The bare-root seedlings were grown in the H. H. nursery at Sebastopol, CA and the United States Forest Service Humboldt nursery at McKinleyville, CA. The ponderosa pine planted in McCloud and white fir planted in Westwood were 1-0 seedlings from H. H. nursery. The remaining seedlings planted in McCloud were 2-0 from Humboldt nursery. The containerized white fir seedlings were 1-0 grown at the Simpson Timber Co. nursery at Korbel, CA. The single site at McCloud and the two sites at Westwood had been mechanically scarified the previous year, with an estimated 15 cm of top soil removed. In Westwood one site was additionally ripped along planting rows to a depth of 30 in. (1 in. = 25.4 mm) after scarification. The single site at Mooreville had been clear-cut the previous year and had no site preparation. Site quality was poor at Westwood, intermediate at McCloud, and good at Mooreville. *Pt* spores were extracted from sporocarps collected in the preceding autumn in the Siskiyou Mountains and stored at 1°C until used (Marx 1976).

Experiments were in a completely randomized design, with the initial experimental unit a row of 16 seedlings planted at 2-m spacing. For white fir, each treatment was replicated eight times. First, 296 seedlings were randomly selected from the total lot supplied for the planting site. These were then randomly divided into 16 groups of 16 seedlings, each group for a row of 16 seedlings. Roots of each group were then dipped in a water—vermiculite slurry. Eight groups were then planted in the eight rows randomly assigned as controls in the overall design. Seedlings of the remaining eight groups were inoculated by enclosing the slurry-dipped roots of an individual group in a large polyethylene bag containing *Pt* spores. Gentle tapping on the bottom of the bag produced a cloud of spores which coated the roots. When spores had settled, seedlings were removed and planted, each group to one of the remaining rows among the controls in the overall randomized design. For species other than white fir, the same procedures were followed except that only half the number of seedlings were selected and each treatment was replicated by only four rows of 16 seedlings each.

Four weeks later, after the soil had settled and before buds broke, seedling heights were measured.

Twenty additional seedlings randomly selected from each lot of planting stock were brought to the laboratory for measurements of stem diameter, total height, height of live crown, dry weight of crown, and number and length of lateral roots. Presence of mycorrhizae was assessed by estimating proportion of feeder roots colonized in the upper, middle, and lower third of the seedling root system.

In November after the first and third growing seasons, seedling survival was recorded and three seedlings were randomly selected from each row for laboratory measurements as described above.

Survival data were processed by analysis of variance, and growth data by analysis of covariance with initial height as the covariate.

Results and discussion

Examination of seedlings selected at time of outplanting revealed that the containerized seedlings lacked mycorrhizae, whereas about two-thirds of the short roots of bare-root seedlings were colonized by *Thelephora* spp. When seedlings were examined at the end of the first growing season in the field no *Pt* mycorrhizae were found. Microscopic examination of the roots revealed large numbers of *Pt* spores still present on root surfaces. All seedlings were completely mycorrhizal, presumably either with *Thelephora* spp. or with fungi native to the sites. At the end of the third growing season occasional *Pt* mycorrhizae were seen on the Westwood seedlings. These seedlings also had *Cenococcum geophilum* Fr. mycorrhizae. No *Pt* mycorrhizae were found in the seedlings examined from the other sites.

Survival was high for all species. Spore inoculation significantly reduced 1st-year survival of white fir planted in Westwood and red fir planted in McCloud (Table 1). *Pt* spores are hydrophobic, so we suspect that an excessive spore coating on roots of inoculated seedlings inhibited water uptake by the seedlings, thereby increasing first growing season mortality. Controls and inoculated treatments did not differ significantly at the end of the 3rd year at any site. The failure of spore inoculation to produce mycorrhizae may be due in part to antagonism by resident fungi in the soil and to endogenous inhibitors in spores that limit germination when spores are massed. Marx (1976) reported that *Pt* mycorrhiza formation is reduced when spore inoculation rate exceeds that which produces the most mycorrhizae.

The only significant difference in growth between control and inoculated seedlings occurred at the end of the first growing season on white fir at the scarified but not ripped Westwood site. Inoculated seedlings had significantly greater total heights and crown heights than did controls. At the end of the 3rd year at this site, heights no longer differed.

Analysis of seedling growth parameters grouped by treatment and compared by site preparation at Westwood revealed that, by the third growing season, stem diameter, total height, and live crown height of white fir were significantly greater in scarified and ripped ground than in scarified only. Ripping may favor seedling growth by encouraging development of deeper root systems (Hermann 1977). Firs may be particularly responsive to ripping, because they are more sensitive to soil compaction than other coniferous species (Minore et al. 1969). Moreover, rip rows provide partial shade at the soil line and thereby reduce chances for heat damage to stems.

Acknowledgements

We thank W. H. Beaty and Associates Inc., Champion International Co., and Soper-Wheeler Co., for their cooperation. We also thank John Hazard and Pat Williams of the United States Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station for statistical analyses.

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